Modeling the Benchmark Active Control Technology Wind-Tunnel Model for Application to Flutter Suppression

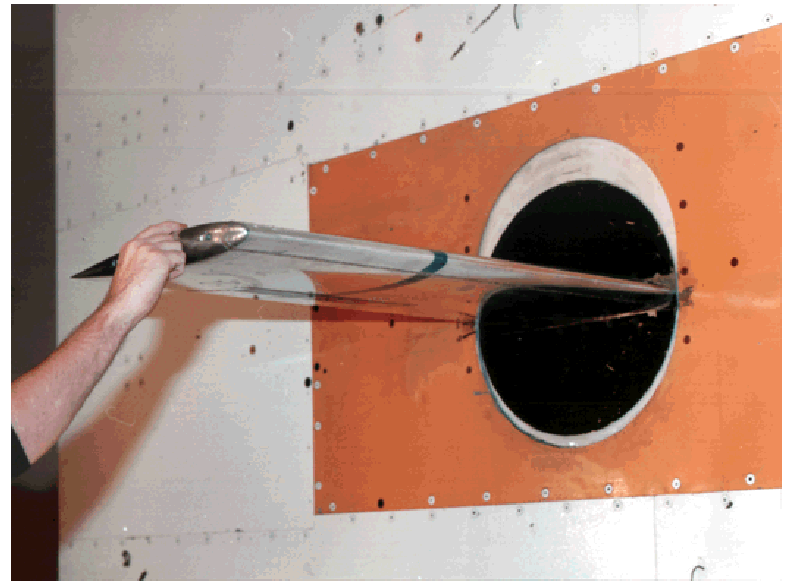
Martin R. Waszak

Langley Research Center
Dynamics and Control Branch

AIAA Atmospheric Flight Mechanics Conference
San Diego, California
July 29 - 31, 1996

Outline

- **BACT Overview**
  - **Program**
  - **Wind-Tunnel Model**
- **Modeling Requirements**
- **Modeling Approach**
- **Model Accuracy**
  - **Static Equilibrium**
  - **Flutter Properties**
  - **Turbulence Response**
  - **Frequency Response**
- **Concluding Remarks**

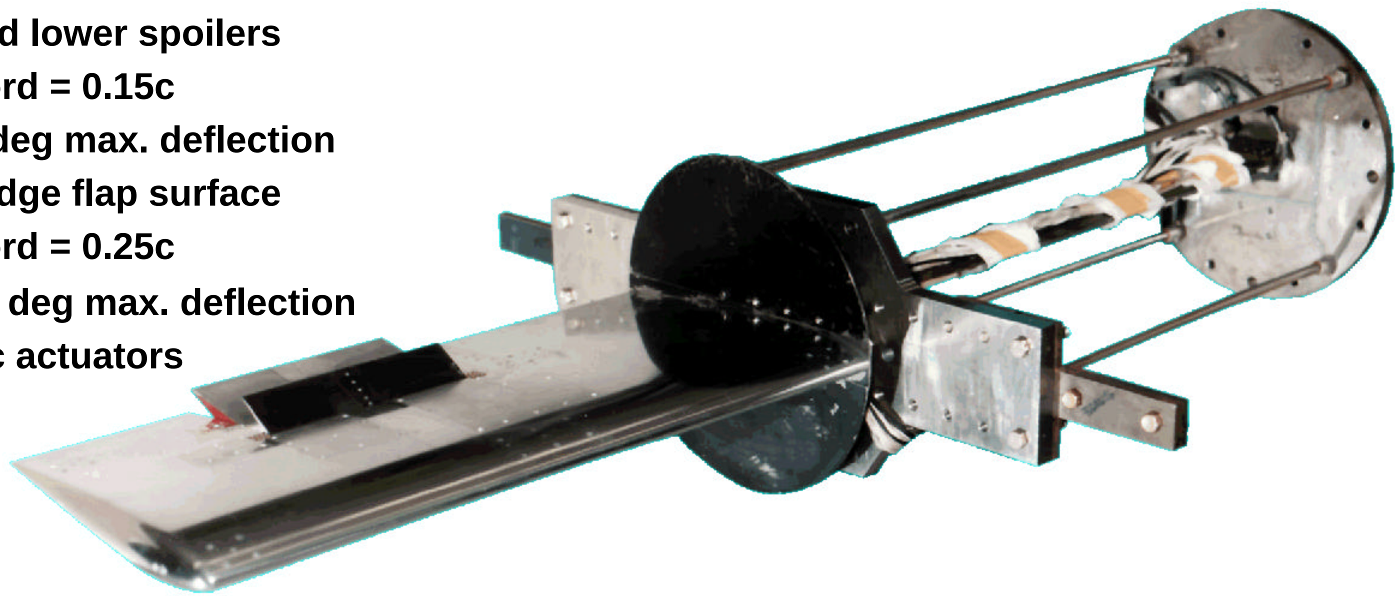


BACT Program Overview

- **Benchmark Aeroelastic Models Program**
  - **study physics of aeroelastic phenomena**
    - » **classical transonic flutter “bucket”**
    - » **shock induced instabilities**
    - » **dynamic vortex-structure interaction**
  - **data to validate steady and unsteady aero codes**
  - **active control of aeroelastic systems**
- **Benchmark Active Control Technology (BACT)**
  - **high quality unsteady aero data near flutter**
  - **active flutter suppression**
    - » **innovative control concepts - spoilers and multivariable**
    - » **innovative design methods - H_∞, μ-synthesis, neural nets**
  - **evaluate on-line controller performance assessment tool**

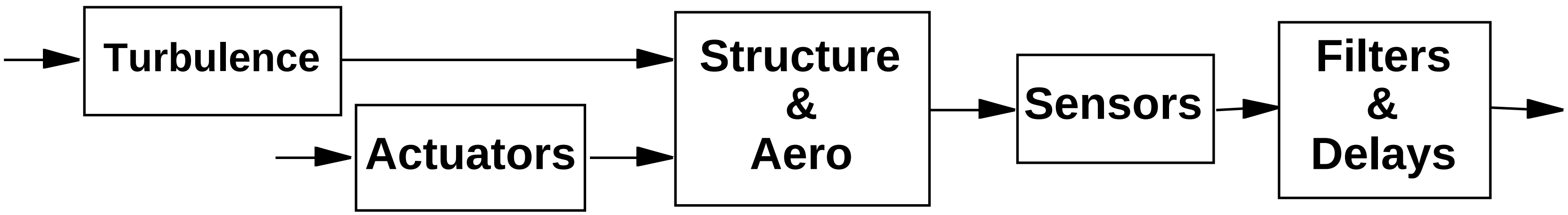
BACT System Overview

- **Pitch and Plunge Apparatus (PAPA)**
  - **2-DOF : pitch and plunge**
  - **5-6 deg max. rotation**
  - **1.5 inch max. deflection**
- **Wind-Tunnel Model**
  - **rigid NACA 0012 airfoil**
  - **AR = 2 (c = 16 in., b = 32 in.)**
- **Control Surfaces**
  - **span = 0.3b, centered at 0.6b**
  - **upper and lower spoilers**
    - » **chord = 0.15c**
    - » **45 deg max. deflection**
  - **trailing edge flap surface**
    - » **chord = 0.25c**
    - » **±15 deg max. deflection**
  - **hydraulic actuators**
- **Instrumentation**
  - **4 accelerometers in corners of wing**
  - **pitch angle sensors**
  - **70 pressure transducers**
    - » **58 @ 0.6b (incl. control surfaces)**
    - » **17 @ 0.4b**
  - **add'l transducers on splitter plate**
  - **accels and strain gauges on PAPA**



Modeling for Flutter Suppression

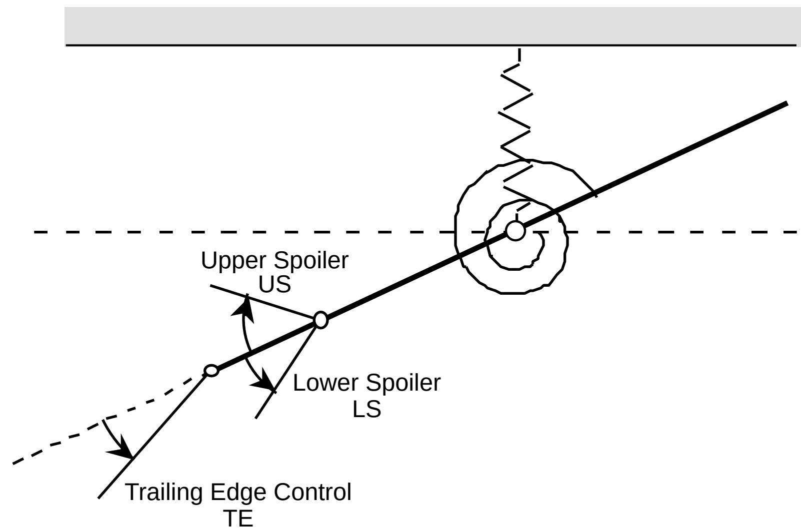
- **Model elements**
  - structural dynamics
  - steady and unsteady aerodynamics (including control effects)
  - turbulence effects
  - actuators, sensors, controller effects



- **Special features**
  - accurately characterize dynamic response
    - » flutter frequency range
    - » wide range of Mach and dynamic pressure
    - » due to spoilers (not possible with “standard” modeling method)
  - characterize effects of key parameter variations
    - » sensitivity analysis
    - » uncertainty models

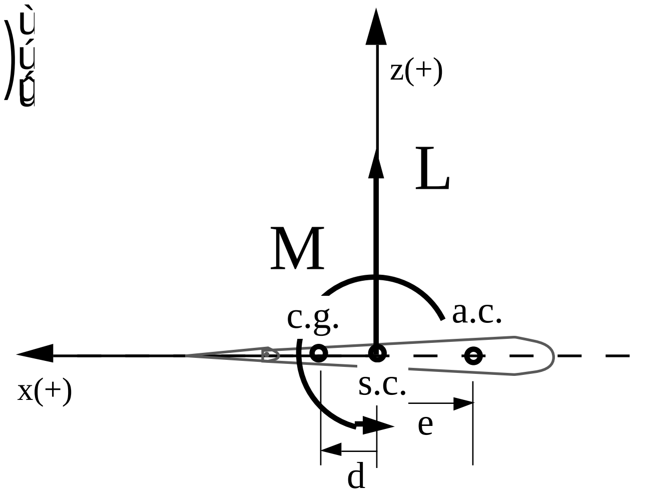
Modeling Approach

- **Idealized structure**
  - **2-DOF : pitch and plunge**
  - **linear**
- **Aerodynamics**
  - **linear**
  - **no lag terms,** ω**c/2U**$_0 = 0.044$



$$\alpha(t)\quad \theta_T + \theta(t) + \frac{\dot{h}(t)}{U_0} + \frac{\ell(x)\,\dot{\theta}(t)}{U_0} - \frac{w_g\,(t)}{U_0}$$

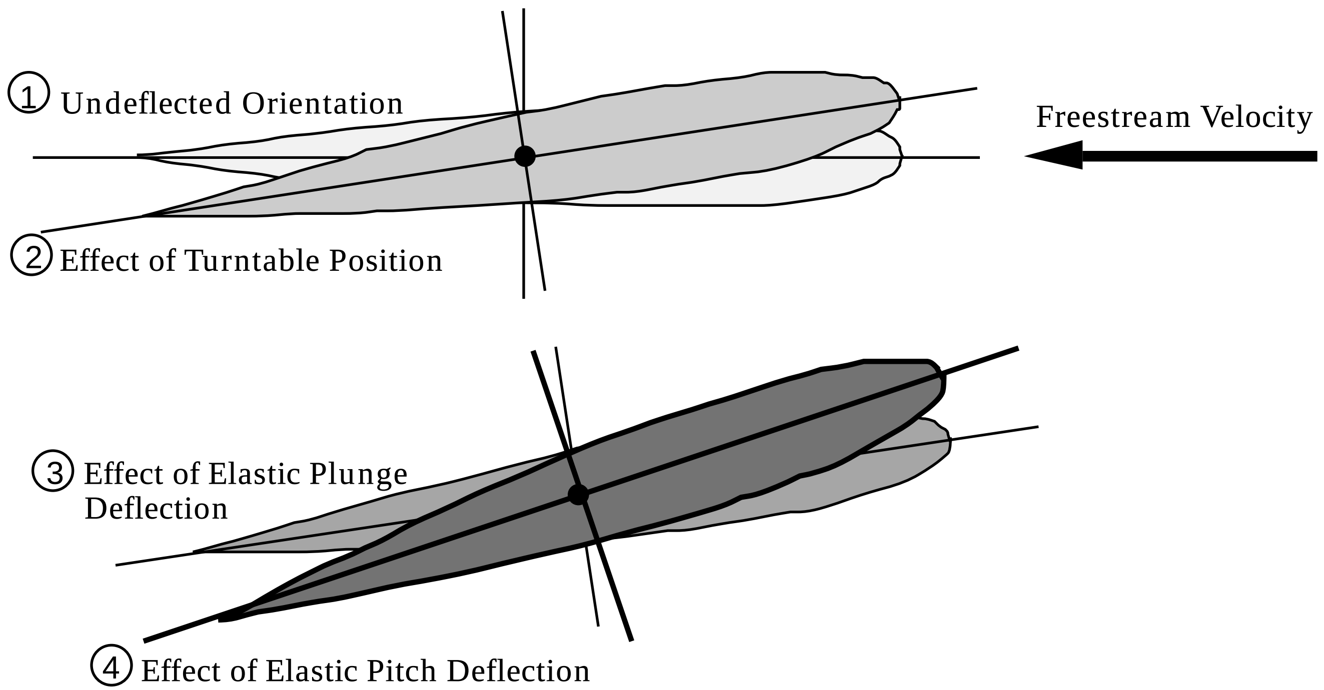
$$L = \bar{q}S\left[C_{L_0} + C_{L_\alpha}\alpha + C_{L_\delta}\delta + \frac{\bar{c}}{2U_0}\left(C_{L_{\dot{\alpha}}}\dot{\alpha} + C_{L_q}q + C_{L_{\dot{\delta}}}\dot{\delta}\right)\right]$$



- **EOM's**
  - **Lagrange's equations**
  - **Principle of virtual work**
  - **Experimental data in numerical model**

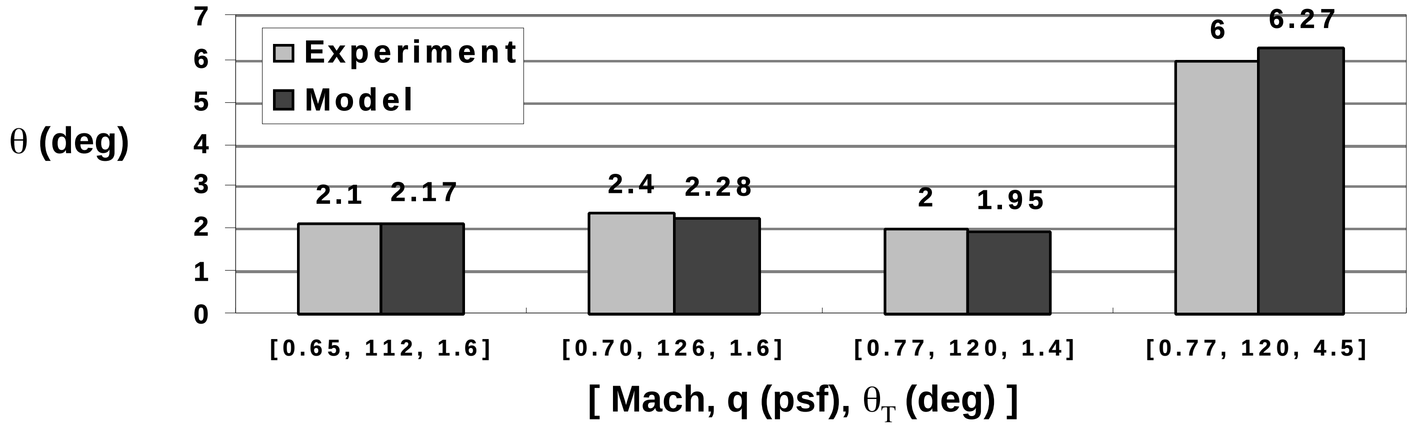
BACT Dynamic Response

Decomposition of Response

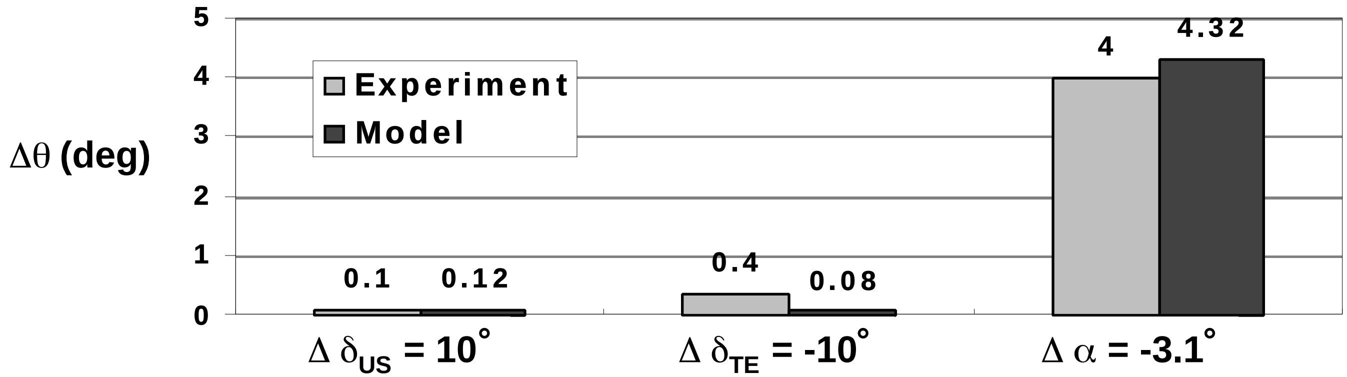


Model Accuracy - Static Equilibrium

- **Equilibrium Pitch Angle**

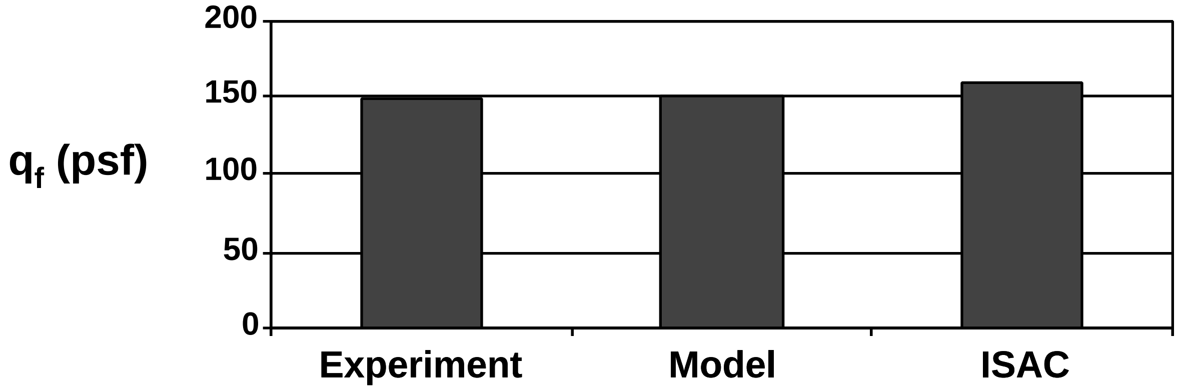


- **Pitch Effectiveness**

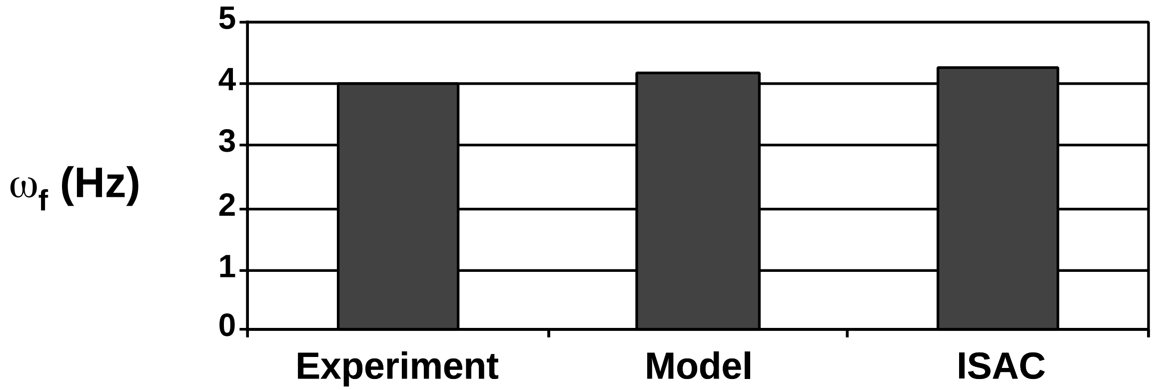


Model Accuracy - Flutter Properties

- **Flutter Dynamic Pressure (M = 0.77)**



- **Flutter Frequency (M = 0.77)**



Model Accuracy - Disturbance Response

- **Turbulence Model**
  - **Dryden form**
  - **scaled for TDT turbulence levels in air**
  - **parameterized by airspeed (U = 100, 200, 300, 400 fps)**

- **RMS Turbulence Response (U = 400 fps)**

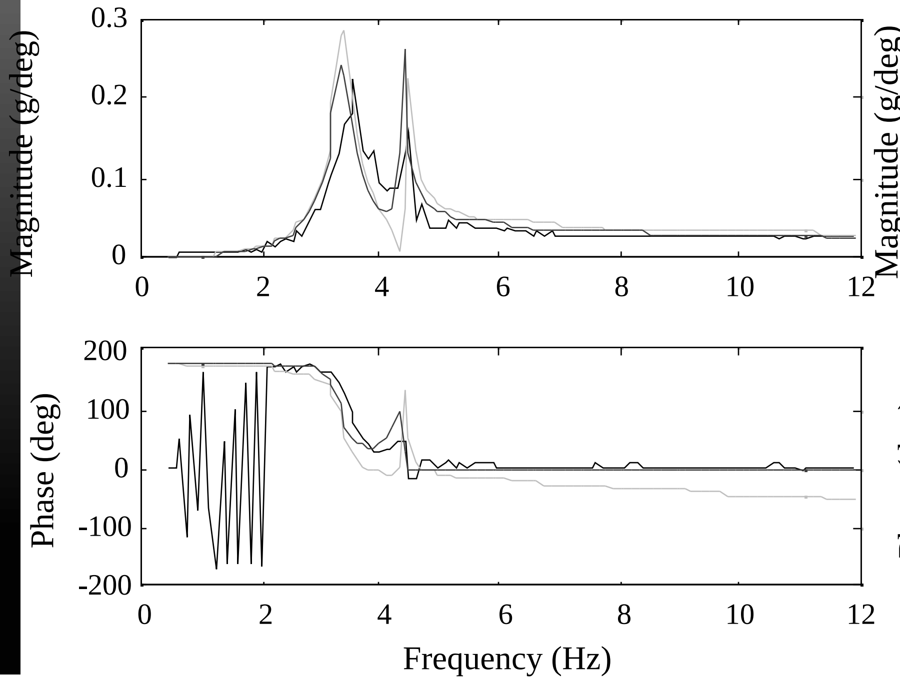
	RMS Trailing Edge Inboard Acceleration (g's)		
q_{norm} (psf)	Experiment	Model	% Error
$0.75*q_f$	0.0207	0.0188	-9.2
$0.90*q_f$	0.0340	0.0350	2.9

Model Accuracy - Frequency Response

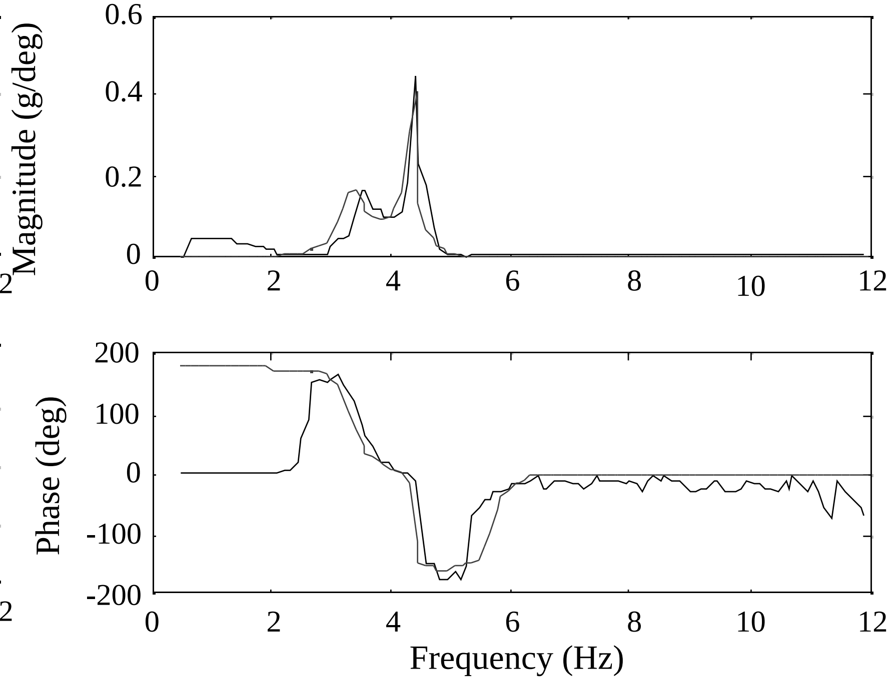
- **Subcritical Condition : M=0.77, q=125 psf**
- **Trailing edge inboard acceleration (g's)**

———	**experiment**
- - - - - -	**model**
....	**ISAC**

Trailing Edge Flap



Upper Spoiler



Langley Research Center

Flight Dynamic and Control Division

Concluding Remarks

- **Simple yet complete model for control system design**
  - **parametric**
  - **modular**
  - **based on most accurate data available**
- **Accuracy demonstrated**
  - **static equilibrium**
  - **flutter properties**
  - **turbulence response**
  - **frequency response**
- **Implemented in Matlab®/Simulink®**
- **Used in design of several control laws**
  - **classical**
  - **H∞ and μ-synthesis**
  - **neural nets**